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RESEARCH PAPER

Responses of some landscape trees to the drought and high temperature events during 2006 and 2007 in Yamaguchi, Japan

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Abstract: Extreme weather events were analyzed based on the meteorological data from the year of 1967 to 2007 for Yamaguchi, Japan. The responses from landscape trees were also investigated mainly by the analysis of image pixel and spectral reflectance. Results show that after the dry, hot and windy summer in 2007, many landscape trees in Yamaguchi City tended to respond the extreme weather events by reducing their leaf surface area and receiving less radiation energy. Premature leaf discoloration or defoliation appeared on some landscape tree species and leaf necrosis occurred on tip and margin of many Kousa dogwood (*Cornus kousa*) trees at unfavorable sites. Described by image pixel analysis method, the leaf necrotic area percentage (LNAP) of sampled dogwood trees averaged 41.6% and the sampled Sasanqua camellia (*Camelia sasanqua*) tree also showed fewer flowers in flower season of 2007 than that in 2006. By differential analysis of partial discolored crown, it presented a logistic differential equation of crown color for sweet gum (*Liquidambar styraciflua*) trees. It suggested that the persistent higher temperature and lower precipitation could be injurious to the sensitive landscape trees at poor sites, even in relative humid area like Yamaguchi.

Keywords: extreme meteorological event; drought and high temperature; landscape tree; image pixel analysis; response

Introduction

In recent years, the significant characteristics of climate variation in Japan manifested that the numbers of abnormal lower air temperature decreased and of extreme higher air temperature (>35°C) strikingly increased (Kurihara 2007). Moreover, the days of no-rain (Kimoto et al. 2005) and of heavy rain over 100 mm or 200 mm show a rising trend (Kurihara 2007). Therefore, a tendency of adding probability of the extreme weather events characterized by higher temperature and both lower precipitation and higher precipitations would be expected (Meehl and Tebaldi 2004). Under the condition that the total global precipitation does not increase, the increasing rainfall in one region implied the reduction of the precipitation in other area. In the same region, the seriously positive gain of rainfall in a period of time seems to induce the coming of dry period. The disproportional changes in the upper end of the precipitation frequency distribution in the United States, most area of Canada and northeast Mexico may be one special case (Groisman et al. 2007), and the drought in 1994 after the year with heavy precipitation in 1993, the persistent less rainfall after the typhoon 0613's hit and the extreme meteorological event in Yamaguchi, Japan in 2007 should be another.

In Japan, the perfect irrigation system enhanced the ability to prevent the paddy rice fields from catastrophic drought, so that the rice-crop index in most prefectures of Japan remained near 100% to normal during the extreme weather event in 2007. However, many of the rainfed growing forests and landscape trees showed different abnormalities in the same times (Kotani 1997). The extreme meteorological event of high temperature and low precipitation affected the plants around invisibly perhaps injured to them (Ciais et al. 2005), even to the perennial trees (Pichler & Oberhuber 2007). For example, in 1994 the paddy rice in west Janpan (Yamamoto et al. 1996) and forest trees (Kotani 1997) suffered from the extreme droughty and hot weather. Historically, in the early 1930's the severe drought at the central states of the United States and unusually dry weather in Australia in 1965, many trees presented early defoliation, leaf scorching, and discoloration. (Kozlowski 1976). These kinds of extreme climate even trigger or accelerate the tree mortality (Guar & Taylor 2005), forest decline (Jurskis 2005), forest defoliation (Zierl 2004), reduction of radial growth of trees (Pichler & Oberhuber 2007), wide-spread primary productivity reduction (Ciais et al. 2005; Barber et al. 2000), particularly in Mediterranean region (Bussotti & Ferretti 1998), Australia (Jurskis 2005) as well as the specific area and limited sites (Van der Werf et al. 2007) in some countries.

Plants respond to environmental stresses from unfavorable extreme conditions with characteristics of species-specific and in different patterns. For example, plants in arid habitats are nor-

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mally exposed to a range of interacting stresses and tend to develop deep and/or extensive root system and high value of root/shoot ratio (Fitter & Hay 2002; Kremer 1983). As the response to unfavorable extreme droughty and hot stresses, plants often show chlorosis and necrosis (Treshow 1970). Many tree species also tend to reduce their leaf surface area (Orshan 1954) by shedding leaves and receive less radiation energy by change their leaf color during extreme dry and hot summer days (Kozlowski 1976; Fitter & Hay 2002).

Following the abnormal droughty spring, hot and dry summer in 2007 in Yamaguchi, many landscape trees showed protective responses, especially the trees planted on coarse sand soil, rock mountain site and the site with root growing limitation. Many Kousa dogwood trees had leaf necrosis on tip and margin from late August, thus making the crown of them discolored in different scales. Leaves on particularly the leader and upper crown branches of sweet gum tree began to turn dull colored from mid-September and reddish-brown or purples by mid-October. All of leaves of some sasanqua trees also defoliate in late August. During the flower season in 2007, the number of flowers on these trees was significantly fewer than that in 2006 season.

As a repaid and non-destructive approach, the image pixel color system analysis (Adamsen et al. 1999; Kawashima & Nakatani 1998; Wang et al. 2008; Cai et al. 2006) and spectral reflectance analysis (Carter et al. 2001) used in measuring plant characters can be found in many reports. Image color analysis has also been used in estimating the temporal trends of flower numbers (Adamsen et al. 2000). In this study, the image pixel analysis was used in determining leaf necrosis of dogwood, partial crown discolor of sweet gum tree as well as flowering status of sasanqua triggered by extreme meteorological events in 2007 and by Typhoon 0613. The spectral reflectance characteristics of sweet gum and dogwood leaves were analyzed by using spectral measuring method. The aim of the present study was to show the facts of protective responses and species-specific characteristic from these landscape trees to the extreme hot and droughty meteorological events with the nondestructive and noninvasive method.

Materials and methods

The meteorological data

The annual, monthly, daily meteorological data from the year of 1967 to 2007 for Yamaguchi and other 150 observatories was obtained from Automated Meteorological Data Acquisition System (AMEDS) of Japan. The investigated trees were around an area 0.43 to 1.26 km from the Yamaguchi meteorological observatory. The data was analyzed and described by common statistic parameters.

Leaf necrotic area percentage (LNAP) and Normalized Difference Vegetation Index (NDVI) $_{765/679}$ of dogwood leaves

The sampled dogwood trees, about 6-year old and 3−4 m high, were planted at the sites on an ancient riverbed (Sakaue & Ijiri 1972; Miura & Ono 1972) area and the former athletic track around a park in Yamaguchi City. A total 61 individuals were sampled. In the study, the image G/R (Green/Red) value and LNAP for leaves were determined by analysis of scanned images and a total of 560 leaves were scanned with a flat bed scanner (Canon d125u2).

LNAP was measured by getting pixels of overall leaf and the green part for each leaf. The LNAP was calculated by the following equation.

$$LNAP = 100 - (\frac{PGAL}{POL} \times 100) \quad (1)$$

where *PGAL* is the pixel number of green area of the leaf and *POL* is the pixel number of overall leaf.

The spectral reflectance for leaves with varied LNAP was measured by a radiometer EKO-MS720. Its resolution of spectra is 10 nm, interval of wavelength 3.3 nm, and the specified wavelength ranges from 350 nm to 1050 nm. Leaves were measured with special method at indoor environment and the radiometer was mounted on a tripod 30 cm above the sample leaves. The sample leaves were smoothly filled in a tray in 20 cm × 30 cm × 4 cm size and vertically measured under 40 w incandescent lamp light. A 25° of Field of View (FOV) was selected and the area coverage was 139 cm^2. Measurements were controlled by a piece of white paper corrected by standard white board of barium chloride and two duplications for each sample were conducted at different position of the tray. The spectral reflectance was used to calculate the NDVI $_{765/679}$ by Equation (2).

$$NDVI_{765/679} = \frac{NIR_{765} - VIB_{679}}{NIR_{765} + VIB_{679}} \quad (2)$$

where NIR_{765} is the spectral reflectance at 765 nm in near-infrared region, VIB_{679} is the spectral reflectance at 679 nm in visible region.

Analyzing discolored crowns of sweet gum trees

During the abnormal meteorological event, a lot of investigated sweet gum trees discolored from top to base of crown. The sweet gum trees analyzed in the study were single landscape trees along the high way or streets. They were visually scaled into classes of entire crown green, <1/2 crown discolored, and >1/2 crown discolored. The number of every scale was visually counted *in situ*.

In the study, the *G/R* value in RGB system was used to express the discoloration of the sweet gum crown. The images for calculation of G/R_{cs} (*G/R* value of crown sections) were taken outdoors by using a CCD digital camera (Canon ixy60) with 5.03 million pixels after discolor symptoms perfectly appeared. The crown images were equally divided into 10 sections and the $G/R_{cs,}$ values were determined by Equation (3), which was a proportion of green value of crown section to red value of the same

crown section.

$$G/R_{cs} = \frac{\sum_{i=0}^{255} N_i \times i \Big/ \sum_{i=0}^{255} N_i}{\sum_{j=0}^{255} N_j \times j \Big/ \sum_{j=0}^{255} N_j} \qquad (3)$$

where G/R_{cs} is the G/R value of crown section, N_i is the pixel number in i (green) gradation, i=0,1,2,……,255. N_j is the pixel number in j (red) gradation, j=0,1,2…255.

The G/R_{vcs} is one kind of G/R_{cs} value for crown sections divided from base to top of the crown. The G/R_{hcs} is also a type of G/R_{cs} value for crown sections divided from left or leeward to right or windward of the crown. Before getting pixel data, the image was hand prepared by eraser of Photoshop to remove the objects except the objective crown. Then the Red (R) and Green (G) values are read from the average histogram value of individual crown extracted by tools of Photoshop.

It is observed that the relative G/R_{cs} (RGR) of injured crowns decreased from proximal to distal in the manner of logistic differential function as Equation (4).

$$RGR(n) = \frac{k}{1+e^{a-rn}} \qquad (4)$$

where *RGR(n)* stands for relative G/R_{cs} (refer to Equation 5) index at n section, K is the maximum value that the G/R_{cs} can reach, the r and a are constant, and n is the number of crown sections.

$$RGR_i = \frac{100 \times (G/R_i - G/R_{\min})}{(G/R_{\max} - G/R_{\min})} \qquad (5)$$

where G/R_i is the G/R value for i section, G/R_{min} and G/R_{max} are the minimum and maximum G/R values in all sections, respectively.

Estimation of flowering pixels and flower number of sasanqua

The showy red/pink flowers of sasanqua trees become proper character to analyze its response to the extreme meteorological events. In the study, we took the photo images from the same sasanqua tree on the same day in 2006 and 2007 flower season, respectively. The flower number was visually counted from image and the flower pixels were directly read from histogram value of Photoshop in which flowers were extracted by selection tools.

Results and analysis

Extreme meteorological events during 2006 and 2007

The AMeDAS observation from the beginning of 1967 in Yamaguchi shows that the annual mean temperature drew a fluctuated increasing line (Fig. 1-a), similar to the most of other cites in Japan. Although the annual precipitation almost remained at the same level (Fig. 1-a), it turned to raise the fluctuations of their standard deviation in recent 21 years, especially in the second half of a year (Fig. 1-b). Integrated the meteorological events from 1967 to 2007, a tendency of more negative extreme spread value of the precipitation-temperature proportion (P/T) can be found, with less positive extreme values in Yamaguchi from 1987 to 2007 (Fig. 1-c). The integrated result indicated a trend of more years with high temperature and low precipitation and less years with low temperature and high precipitation. Meanwhile, the occurrence of strong typhoons, gust wind speed over 33 m/s, increased during 1987 and 2007 comparing to that from 1967 to 1986, and the standard deviation of the former also raised (Fig. 1-d line). The mean value of precipitation 44 days after strong typhoon's hit and rainfalls in the day of strong typhoon's hit were both lower during 1987 and 2007 than that from 1967 to 1986. The standard deviation for both of them got larger during 1987 and 2007 than from 1967 to 1986 (Fig. 1-d histogram). Therefore, it seems that the probability of extreme weather event of high temperature and low precipitation increased in local area under this situation.

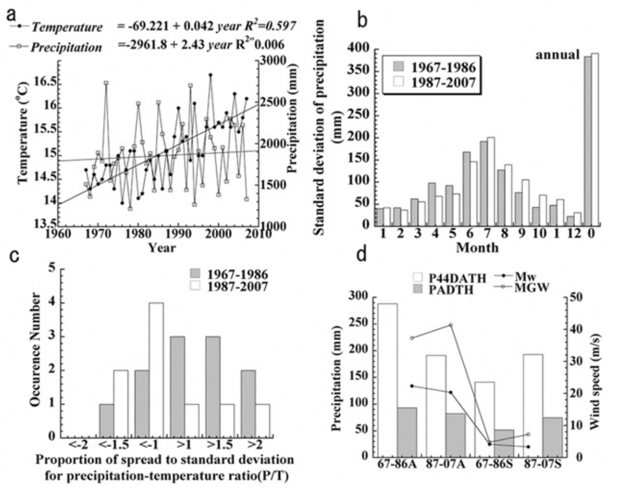

Fig. 1 Characteristics of climate change in Yamaguchi, Japan. Fig. 1-a represents the temporal series of annual mean temperatures and precipitation from 1967 to 2007, which appeared a slant and a level line for temperature and precipitation, respectively; Fig. 1-b shows the yearly and monthly distribution characteristics of standard deviation of precipitation in 1967−1986 and 1987−2007 for Yamaguchi City; Fig. 1-c presents the occurrence number in different folds to the standard deviation value of precipitation-temperature ratio for Yamaguchi; Fig. 1-d is a graph of max gust wind speed (MGW) and max wind speed (Mw) for strong typhoons whose gust wind speed is over 33 m/s, the precipitation in the day typhoon's hit (PADTH) and the rainfall 44 days after typhoon's hit (P44DATH).

The meteorological characteristic during the years 2006 and 2007 in Yamaguchi City, Japan showed a sharp contrast (Fig. 2). The plentiful precipitation in East Asian rainy season (Fig. 2-a), strong typhoon with less rainfall in mid-September, and higher temperature associated with almost no rainfall in October became the extreme meteorological events in 2006 (Fig. 2-a, 2-b,

2-d, 2-e). The less rainfall after strong typhoon 0613's hit almost lasted through the entire 2007 growth season (Fig. 2-a). The extreme meteorological event in 2007 is expressed for its less and uneven precipitation, lower relative humidity and higher temperature than that of normal year (1967 to 2007, Fig. 2-a, 2-c, 2-d, 2-e, 2-f). It took the first rank of annual minimum relative humidity (Fig. 2-c), third rank of minimum annual precipitation (Fig. 2-a) and third rank of annual maximum value of mean temperature during these 41 years (Fig. 2-e). Particularly, the new records of many monthly meteorological variables were rewritten during this period (Fig. 2).

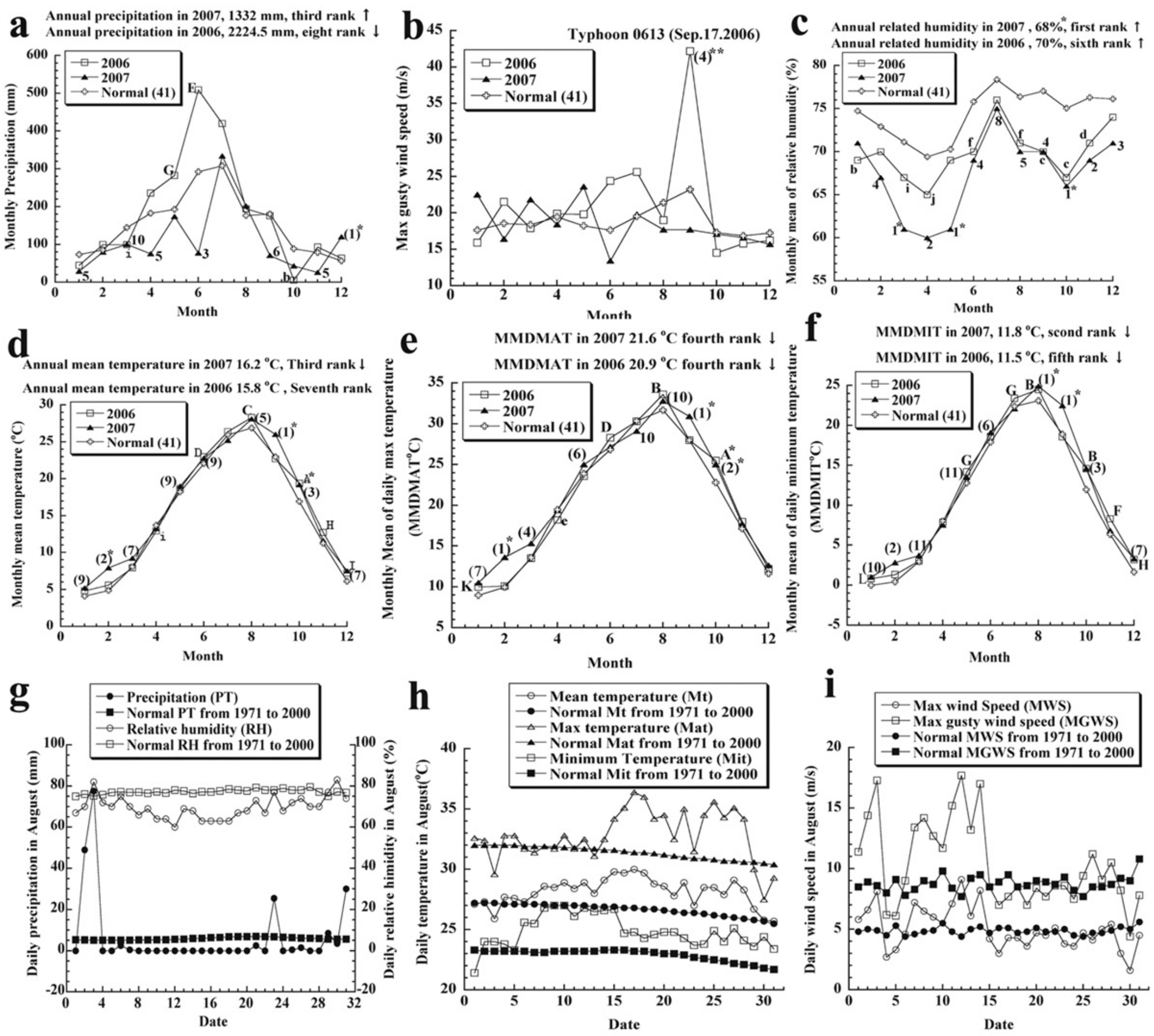

Fig. 2 Extreme meteorological event during 2006 and 2007 in Yamaguchi and their comparison to normal year during 1967–2007 In which, the extreme record in 2006 was marked with capital letters for descending order, small letters for ascending order; and numbers for ascending order, numbers with bracket for descending order in 2007. The value with * mark means its ratio of spread value to standard deviation was more than 2.0. The weather characteristics in August, 2007 were described from Fig. 2-g to Fig. 2-i. They present daily precipitation, daily relative humidity, normal value (1971-2000) of precipitation and relative humidity in Fig. 2-g; mean temperature, max temperature, minimum temperature and normal value of them in Fig. 2-h; max wind speed and gusty wind speed in August and normal values of them in Fig. 2-i.

The extreme weather from August 7 to August 18 can be considered as the key of extreme weather event in August 2007 in Yamaguchi. Although hit by typhoon 0705 on August 3, 2007, its max wind speed was lower than 10 m/s (Fig. 2-i) accompanying with heavy daily precipitation (77.5 mm, Fig. 2-g) and not very higher temperature (daily highest temperature 29.8°C, Fig. 2-h) in Yamaguchi. Then, more than 10 days anticyclone weather occurred. During these days, as the average temperature and minimum temperature maintained higher than the normal year (1971–2000), the max wind speed and gusty wind speed reached the peaks at 9.1 m/s and 17.7 m/s (Fig. 2-i), respectively, associated with no rainfall (Fig. 2-g). Meanwhile, the relative humidity

drew a ‘U’ shaped curve (Fig. 2-g) and the period of no rain lasted for 17 days. All of these led to a foehn like weather.

Responses of landscape trees to extreme weather events

From the end of the strong typhoon 0613’s hit to the late of 2007, the ratio of spread value and standard deviation for 14 meteorological variables exceeded 2.0 (* in Fig. 2) and most of them made a new record. The annual precipitation in 2007 was lower and uneven, which was 71.6% of that in normal year. The annual mean temperature in 2007 accounted for 107.3% of that in the normal year in Yamaguchi. Although the precipitation set up a new record of maximum monthly precipitation in Dec. in Yamaguchi, it was too late to prevent the trees from responding to the hot, dry environment; as a ruslt, various symptoms appeared on many landscape trees, especially the trees planted on the poor soils and the sites with root growing limitation etc. A lot of Japanese red pines (*Pinus thunbergii*) on mountain sites even died, whose needles turned brown first. Some deciduous tree species dropped partial leaves early from late August. The other tree species may be affected by it without visible signs.

During the hot and dry summer, premature discolored sweet gum leaves on particularly the upper crown were noted in 2007. Leaves of sweet gum tree began to turn leaf color from dull in mid-September to reddish-brown or purples by mid-October (Fig.3-b). In contrast, before mid-September the normal growth of non-discolored leaf at left half of crown (Fig.3-a) of sweet gum trees benefited from the plentiful precipitation in the first eight months in 2006 (Fig.2-a). Although no such kind of dry and hot summer arose in 2006 as in 2007, the strong typhoon 0613 still induced many sweet gum tree crowns asymmetrically discolored from windward to the leeward (Fig. 3-a) in mid-September. Described by image pixel analysis, the horizontal threshold equation of image RGR values for the crown of sweet gum trees in 2006 showed an inverse logistic equation from leeward of the crown to windward and an approximate horizontal line for the vertical differential (Fig. 3-e). On the opposite, the horizontal differential in 2007 almost presented an approximate level line and an adverse logistic equation for vertical differential from the bottom of crown to the top (Fig. 3-f).

High values of root/shoot ratio can be achieved by reduced transpiring surface or leaf area. The investigation on 381 stocks of sweet gum trees, planted in Yamaguchi City, indicated a large difference between pruned and non-pruned trees responding to droughty environment, even among the trees planted at different side of the same road. According to the Fig. 3-d, seldom of pruned sweet gum trees (Fig. 3-c) became partial or entire crown discolored with the percentage of 90.1, 7.1 and 2.8, respectively, for crowns of entire green, <1/2 discolored and >1/2 discolored. More non-pruned (Fig. 3-b) trees were the partial and entire crown discolored with 22.8%, 44.8% and 32.4%, respectively, for the same scales (Fig. 3-d). It seems that the tree pruning increased the ability to prevent against injury by extreme hot and droughty meteorological event by changing their root/shoot ratio. Pruning is a common practice in landscape tree management and it directly resulted in increasing the root/shoot ratio of pruned trees. For the clear pruned trees with only main stem, the root/shoot ratios almost become ∞ theoretically. It is not surprised that the new pruned sweet gum tree endured more serious hot, dry environment by direct improvement in the metabolic balance, hormone harmoniousness, and especially the change of water relations. Based on the result of spectral reflectance measurement, the red sweet gum leaves reflected more light energy at red spectral region than that of green leaves. While the purple leaves of sweet gum trees reflected near infrared light energy more than that of the green leaves. Only at the visible green region the reflectance of green leaves was greater than that of purple and red leaves (Fig. 3-g). The premature discoloration of sweet gum trees is no doubt to improve the energy balance.

The most obvious response of some sasanqua trees to the extreme weather event in 2007 was defoliation in late August and fewer flowers in 2007 flower season, especially the trees on constricted sites. During the flower season in 2006, full blooming flowers (Fig. 4-a) for the sampled sasanqua tree might profit from the proper precipitation in summer (Fig. 2-a) and the normal growth in growing season. After affected by the extreme meteorological event, the sasanqua tree in the flowering season of 2007 had very fewer flower numbers (Fig. 4-b) for the reason of the summer defoliation. The image flower pixels measured from the same tree in flowing season of 2006 and 2007 also showed big difference (Fig. 4-e). In the flowering season of 2007, no flower existed on upper half of the crown and only fewer flower bloomed at lower half of the crown at investigated time. It suggests that the shading from upper part of the crown benefit the flowers at lower part.

The symptoms of tip and margin leaf necrosis appeared on many dogwood trees on restricted site conditions in Yamaguchi City from late August, 2007, which made the crown discolored in different scales. The LNAP of sampled trees ranged from near 0 (Fig. 4-c) to 100%. It indicated that the serious leaf necrosis occurred on the leaves of dogwood (Fig.4-d). About 40% leaf area of injured dogwood tree was reduced through the partial leaf necrosis by the end of August 2007. The reduced leaf area was coincident with the precipitation of about 40% less than that of normal (Fig. 4-d) during the first nine months. The relevance between the leaf necrosis of dogwood trees and less precipitation should be less doubt. The result is the indirect decrease of water (precipitation) requirement and less radiant energy reception for the living parts of entire tree. On the base of continuative observation, the dogwood trees with symptoms of leaf necrosis in the middle of August in 2008 were less than 1/2 in 2007. The total leaf area reduction in 2008, only 13.2% of the entire leaves, was less than 1/3 of that in 2007 since the sufficient precipitation in the first half-year of 2008.

A significant adverse relationship between LNAP and $NDVI_{765/679}$ value of necrotic dogwood leaves was shown in Fig. 4-f. It also indicated that more spectral at red region was reflected by severe necrotic leaves than that of normal leaves and that less energy was received by the living part of the necrotic trees compared to the normal trees.

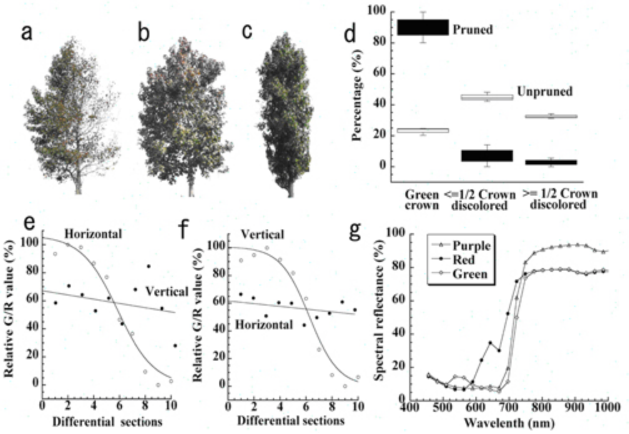

Fig. 3 The abnormal status of sweet gum trees during different extreme weather events in 2006 and 2007. The typical crown status of sweet gum tree in 2006 and 2007 was respectively presented at Fig. 3-a and Fig. 3-b; their differential function of relative *G/R* (RGR) value from vertical and horizontal orientation were respectively showed at Fig. 3-e and Fig. 3-f; The typical crown status of pruned and non-pruned sweet gum trees were respectively at Fig. 3-c and Fig. 3-b; their statistical percentage was presented in Fig. 3-d, where ‘green crown’ is for the entire crown remain green color, ‘<1/2 discolored’ stands for the sweet gum trees which the discolored part of crown is less than 1/2 and ‘>1/2 discolored’ means the discolored part is more than 1/2. Fig. 3-g presented the spectral reflectance curves for green (○—○), purple (Δ—Δ) and red (×—×) of sweet gum leaves at visible and near infrared region.

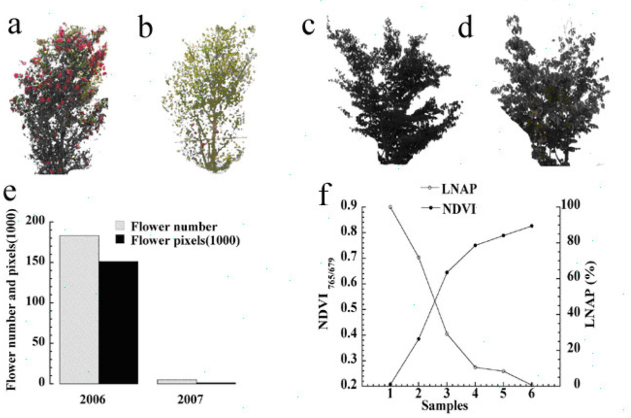

Fig. 4 Different flowering status for the same sasanqua tree in 2006 and 2007 flower season were separately presented at Fig. 4-a and Fig. 4-b, and the flower number and pixel numbers of flowers in Fig. 4-e. The dogwood almost with no necrotic leaves like the crowns before hit by typhoon 0613 in 2006 was shown in Fig. 4-c; the crown with several leaf necrosis after extreme weather event in 2007 shown as Fig. 4-d; the LNAP (○—○) and $NDVI_{765/679}$ (●—●) values of dogwood leaves measured in Oct. 2007 were shown in Fig 4-f, which presented a striking adverse relationship.

Discussion

During the extreme drought and high temperature event in 2007, 20% of the 150 observatories in Japan showed that the precipitation was less than 80% of that of normal year and the temperature was more than 105% of the normal. In Yamaguchi, the extreme hot and dry weather events in 2006 and 2007 made many meteorological variables became the events occurred once more than 40 years, and the complex of these variables may be longer than 50 or 60 years. Although it is related to the global warming still remained unclear, it happened in Yamaguchi under the background of climate change. These changes, especially the higher temperature associated with local drought, will endanger the sensitive landscape trees.

Many kinds of meteorological variables affect plants, directly or indirectly, singly and complexly, rapidly and slowly, as well as persistently and temporarily (Maki et al. 1991). Plants will develop normally as long as each of many environmental factors remains within a critical range. Extreme environmental factors affect the plants comprehensively, and the injuries tend to be most serious and the threshold double decreased when more factors are in the stress status. The most evident responses of some landscape trees to the drought and high temperature event during 2007 in Yamaguchi became one of the cases.

Leaf scorch emerged on many kinds of trees, but is particularly common on shade-love species. Leaves are also predisposed to necroses most severe when a period of cloudy, rainy weather promoting rapid top growth is followed by hot sunny days (Treshow 1970) and there is no enough water supply. During the extreme weather event in 2007 in Yamaguchi, although the precipitation in July got over that in the normal year, this kind of temporary restore of water supply might make the necrosis of the dogwood leaves more serious in late August for the reason of serious water imbalance. This kind of extreme meteorological event can be described as the momentary Mediterranean climate like event.

Although the different tree species may respond water stress and hot, dry wind injury differently, the response always made them varied toward decreasing water loss and accepting less radiation energy. Particularly in summer, root growth is often reduced and stopped by soil water deficit (Kramer 1983). The transpiration cooler imbalance seems to be lethal for plants with the serious drought stress. The reduction of transpiring surface by shedding of leaves has been considered to be the most important factor in survival of many desert plants (Orshan 1954). Although many tropical trees are classified as summer deciduous species, some of them tend to shed their leaves during dry period (kozlowski 1976). Therefore, they are considered as species with characteristics of environment specific leaf shedding. In the late August, many sasanqua trees in Yamaguchi evaded the extreme droughty, hot stress by leaf shedding, which usually did not defoliate in the normal years.

During the growth of trees, if leaves do intercept excessive amounts of solar radiation under conditions of water shortage, survival will depend on convection of excessive heat from the leaf surface of reflection on incident radiation before it can be absorbed (Fitter & Hay 2002). In the present study, red or purple leaves of sweet gum trees resulted in more reflection of light energy in red and infrared ranges than that of green leaves, and the discolored trees accepted less radiation energy from direct sunshine.

During the extreme meteorological events in 2006 and 2007,

two typhoons directly affected the landscape trees in Yamaguchi. One is the Typhoon 0613 characterized by strong wind associated with less rain. After its hit, many crowns of landscape trees become asymmetrically discolored. By contrast, the Typhoon 0705 is characterized by moderate wind and proper precipitation and almost no visible impact on the landscape trees in Yamaguchi. While during anticyclone weather in the mid-August in 2007, the wind seems to play a role in increasing the injury power by hot and dry weather events.

With different genetic characters of leaf structure, the landscape trees of dogwood, sweet gum tree and sasanqua responded the extreme weather events during 2006 and 2007 variedly in Yamaguchi. Although the strong wind with less rainfall in 2006 did not lead the evergreen sasanqua to appear significant, visible disorder, the dry, hot and windy weather event in 2007 caused them into leaf shedding and less flowers bloom in flower season. The leaf necrosis induced by droughty and hot weather event in 2007 may be attributed to the light leaf textural and persistence of the dogwood leaves. The leaf discoloration from upper to the base of the crown for sweet gum trees seems one of the striking adaptive characteristics during the extreme weather event in 2007.

Landscape trees were usually selected and planted for their ornamental values. However, partial landscape trees, aesthetically planted and regenerated at their unfavorable site, are sensitive to the environmental changes. Nevertheless, under the proper stress condition, the ornamental value of many landscape trees is even increased. The response of these trees to the extreme meteorological event may be an effective reference of the climate change. They could become usable resources to study the injury or shock by extreme environment changes, especially for the humid area like Yamaguchi with normal year precipitation 1850 mm. It may also be important feedback information for the construction of artificial ecosystem.

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